ATLANTIS PRESS
Advances in Economics, Business and Management Research, volume 47
International Scientific Conference "Far East Con" (ISCFEC 2018)

Adaptive Management of System Parameters of Maintenance, As Well As Repair and Optimization of Spare Parts, Tools and Accessories of the Integrated Radar System on the Basis of Reliability Model and Control Data

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Abstract— **The paper deals with the development of the adaptive approach method to maintenance (MNT) arrangement and provision of spare parts, tools and accessories (SPTA) for the integrated radar systems (IRS) with the purpose of increasing the indicators of its readiness in the conditions of digital transformation. The method consists in managing the parameters of the system of main-tenance, repair and operating (MRO) and inventory and logistics support (ILS) by analyzing the data of integrated control systems in a real-time environment on the basis of logical and probabilistic model of IRS reliability. For this purpose, it is necessary to solve the task of maximizing the reliability parameters when limiting the value of no-failure operation probability and the total cost of MNT and SPTA. Such adaptive approach to MNT suggests that the technical condition of the product is continuously analyzed on the real time basis by using an integrated control on all admitting nodes. Similarly, an optimal set of SPTA is calculated depending on the current and forecasted values of the technical condition of the system. Within the framework of the proposed adaptive MNT the integrated control should be used on all the nodes where it is possible, and the data on the technical condition are transferred to the server where the optimization task is performed, including forecasting by machine learning methods.**

Keywords— Reliability Engineering, Optimizing, Spare Parts, Adaptive Maintenance, Machine Learning, Predictive Maintenance, Repair, Integrated Radar Systems.

1. INTRODUCTION

The technological leap connected, first of all, with the development of robotics, production automation and the use of predictive analytics, in particular, machine learning, creates new opportunities and prerequisites for the modernization of radio information systems. This allows integrating the data obtained by the integrated control means into the maintenance system to increase the reliability value of the equipment and prolong the time of their uninterrupted operation on the basis of reliability engineering methods [1].

The "smart" production and operation of technically complex systems contains the connected devices exchanging information with each other and with server [2]. Accordingly, the big data are processed by machine learning methods as well as predictive analytics and predictive maintenance [3]. That is why there appear prerequisites for the development of new approaches, including in MRO arrangement. A special role is played by the planned modernization of existing equipment, including equipping it with digital sensors and communication means, which finally determines the nomenclature of the used SPTA [4].

The traditional approach to MNT arrangement based on the periodic scheduled works and repair operations ‘upon fault detecting’ is accompanied by serious expenses, including material ones (need in expensive maintenance operations) and functional ones because of the breaks for the time of repair and maintenance.

As the modern distant radar stations are equipped with regular system of automated diagnostics, a considerable part of faults may be prevented by additional MNT assigned in accordance with the continuous control data [5]. It is also necessary to take into account that particular types of faults may be repaired automatically (for example, some faults of the service software – by reset). Such types of MNT and recovery influence general parameters, in particular, MNT periodicity.

2. RESEARCH METHOD

From the reliability theory viewpoint, the IRS is a complex repairable system, so the main methods to assess its parameters are IRS reliability and risk model-building methods by means of reliability block diagram (RBD) techique [6] and Markov simulation techique [7]. These methods are widely used in the theory of controlability [8] in assessing the properties of the object for monitoring (diagnosis). We will consider the possibility of using data from the means of the built-in system for monitoring technical condition of the IRS to control the maintenance parameters by using an information and calculating system.

The main purpose of the paper is to increase the value of IRS availability by controlling the parameters of the maintenance system while limiting the relability value and the total cost of the maintenance. Mathematically this task can be formalized as follows [8]: to calculate the maximum of availability CR (t, P(t), …) limiting its reliability parameters, in particular, the value of reliability P(t)≥ Prequired and the total cost of carrying out MNT and SPTA [9].

In this statement the availability function CR is used as a complex reliability characteristic and the probability of failure Q(t)=1–P(t) is used as an auxiliary reliability characteristic [10].

The assigned task can be achieved by developing a method of adaptive control of integrated IRS MNT system parameters which means as follows:

- to develop the model of equipment reliability taking into account its controllability, i.e. presence of the integrated control indications coming on the real time basis;there is a number of control parameters that characterize MNT (time until the next MNT,

- the list of planned operations, the current requirements for the complete set of SPTA [11];

- at any time the problem deals with constrained optimization of the availability function where additional condition is e.g. limiting the cost of MNT.

Let's define vector V for a set of process and program operations executed during MNT, the solution of a problem will be such vector V* which will provide maximum value of CR during the considered interval of time in the conditions describing product controllability and features of its restoration. From a formal point of view, the construction of the optimum MNT variant means finding such combination of parameters ΔT, C, t, x and a set of SPTA which will provide maximum CR(t, P), during time (0, T) on the basis of the offered reliability model taking into account possibilities of control, recovery, SPTA, etc. while limiting reliability value and cost

$$M: V^* = \arg\max C_R\,(V, \Delta T, C, t, x, M) \mid P(t) \geq P^{required} \quad C < C^{MAX} \text{ .(1)}$$

where V = V (...) is a vector that describes the variant of MNT and SPTA; V* is a vector describing the optimal variant of the duration and the volume of MNT and SPTA; ΔT is the time interval between the end of the previous MNT and the beginning of the subsequent one; $P(t)$ is an estimated probability of no fault operation $P^{required}$ is the required probability of no fault operation (defined in the TOR) C is a component cost vector; x is a vector of parameters characterizing the condition; M is an IRS reliability model.

Many of the maintenance planning problems involve multiple conflicting objectives [12]. As you can see from (1), the key role is given to the development of the IRS reliability model, i.e. to the model of calculation of readiness indicators and fail safety of IRS components taking into account the structure and the peculiarities of their interaction [13].

Having the solution algorithm for the formulated problem (1), the adaptive MNT system, according to the integrated reliability model (which we have conditionally designated with symbol M), in the consecutive moments of time (with the given periodicity), on the basis of the aggregated information on IRS technical condition, calculates the forecast of reliability parameters of its components and solves the optimization problem formulated in terms of reliability theory, giving recommendations on planning the optimal complex of operations and SPTA set [14].

A practical solution of the constrained optimization problem is complicated because of a large number of factors and characteristics of the IRS and its components, which have different effects on fault statistics. In this connection, it is necessary to take into account the complex multiparameter dependence of CR (t, P). Also, it is necessary to pay attention to additional conditions associated, for example, with a limitation on the total cost of MNT C<CMAX. The solution of the optimization problem for the time t determines the required set of operations of the maintatnance.

The solution of the numerical optimization problem requires a combination of direct search ("scanning") methods necessary for primary (rough) localization of local minimums together with the fast gradient methods determining the solution of the problem of MNT parameters optimization with high accuracy (for example, the fastest gradient descent).

The peculiarity of the problem is the continuous aquisition and refinement of the data on the technical condition [15]. On the one hand, there is a retrospective selection obtained at the moments of time ti. This selection is expressed by a matrix with the number of elements $x \in X$ and instants of failure T characterized by parameters y as well as data on the methods of subsequent recovery z after failure $y \in Y$. Thus, this task includes the classical "learning from examples", i.e. search of dependency models:

$$y = B(x),\; C_R = f(t, x, y, z). \tag{2}$$

It assumes that there are unknown target dependencies — mapping $X \rightarrow Y$ (i.e., sets of description of control data X and possible failures Y). If such dependencies are found (in particular, by using machine learning methods [16]), it allows to develop an optimal complex of adaptive MNT, i.e. to automate the process of working out the corrective actions, depending on the observed control data x(t). Machine learning methods can discover hidden information from complicated data of previous MNT records. Predictive Maintenance can be performed by both unsupervised and supervised methods to avoid future failure [17].

The method of adaptive management of the maintenance system parameters within the framework of the development of the optimal MNT system and SPTA set consists in the following: having the refined dependence models CR=f(t, x, y=B(x),z) and solving the optimization problem (1) at each moment of time, it is possible to form the set of actions for constructing the optimum MNT variant and SPTA set. At the same time it is necessary to take into account that the proposed list of MNT operations depends on different parameters. In particular, the parameters of the task may include continuous dependencies, for example, on the interval between the routine work or on the recovery time [18].

The development of the adaptive management of maintenance system parameters on the basis of the proposed model representation is connected with the creation of the formalized basis which will allow to manage correction of time frame and kinds of maintenance of IRS components on the basis of collecting and processing the diversified information on its condition coming in real time, including taking into account the data on the exploitation of analogues and previous generations and Failure modes and effects analysis (FMEA) [19] (Figure 1).

On the basis of FMEA analysis a matrix of possible types of product failure is formed, ranked by the degree of failures criticality. On the basis of this matrix and with the help of the data on operation of analogues and previous IRS generations, a model of product reliability is formed which, besides parameters, takes into account the data on its current technical condition which are received in real time. FMEA is essential to classify failures according to criticality of the end effects [20].

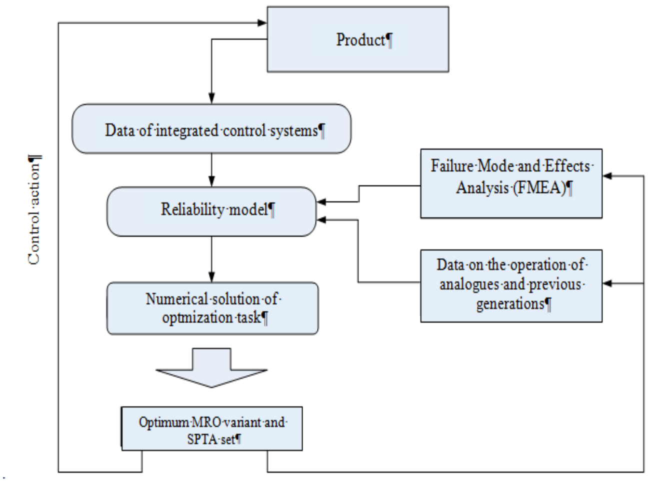

Fig. 1. The general scheme of data processing of technical condition and MRO optimization.

3. Results and Discussion

As a result, by numerical solution of the constrained optimization problem CR (1), it is possible to calculate the shedule of MNT operations and SPTA set which are optimal at the moment from the maximizing reliability viewpoint. When this shedule of MNT and SPTA is approved, the corresponding information is recorded in the model, and the subsequent calculations are carried out taking it into account.

Thus, the solution of the given problem consists in maximizing the product availability function on the basis of the reliability model, in accordance with expressions which take into account the controllability, as well as features of restoration and repair of the IRS components.

Such applications follow in real time and create statistics providing the possibility of risk assessment as a complex indicator of reliability and technical state of the radar; it is ranked by weight, terms, etc. Finally, the proposed method of adaptive maintenance generates a stream of applications for the maintenance of the IRS, which presents the address and nature of the IRS components in a specific format.

4. Conclusion

The paper shows that on the basis of the developed method it is possible to build a system of adaptive MNT and a set of SPTA which will provide maximization of IRS reliability parameters in real time. To determine the composition and the structure of MNT operations, it is the most rationale to combine the application of the mathematical apparatus of the classical reliability theory and modern methods of product design, creation and operation. To calculate the reliability parameters for the product components at any time, it is expedient to use different models serving the basis for the solution of a multiparametric task of finding the optimum combination of control parameters maximizing the reliability parameters within the specified operating time and within the limits of financing.

The combination of control methods for technical condition, reliability theory and machine learning allows to synthesize the experience of development and operation of previous and existing IRS generations and compute the characteristics of their fail safety over time.

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